Recent Activities on Tristan da Cunha Island: Geodetic Installations, Local Tie Measurements and their Analysis

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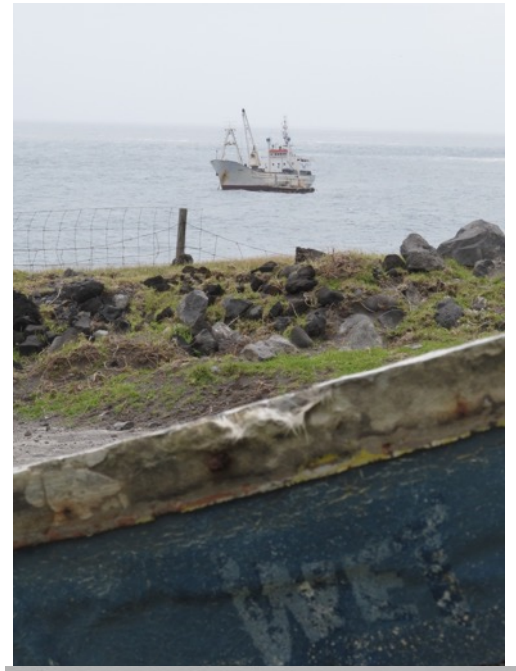
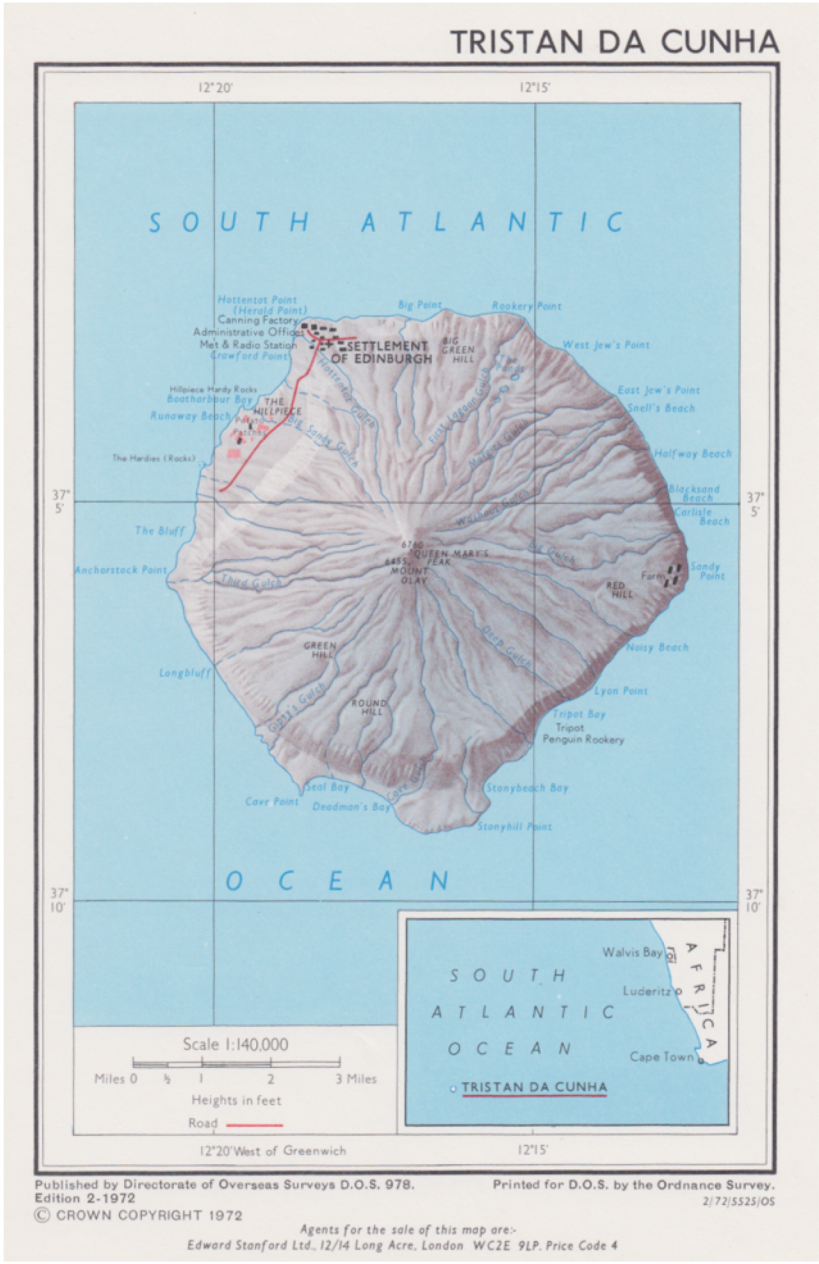



TRISTAN DA CUNHA
POLICE STATION


WELCOME
TO THE
TRISTAN DA CUNHA
SOUTH ATLANTIC
REMOTEST
ISLAND

Overview

- Background
- Objectives
- GNSS Installation
- Tide Gauge Installations
- Benchmark Network
  - Existing Benchmarks
  - New and GNSS Benchmarks
- Tie Measurements – Site survey
- Results
- Conclusions and Outlook

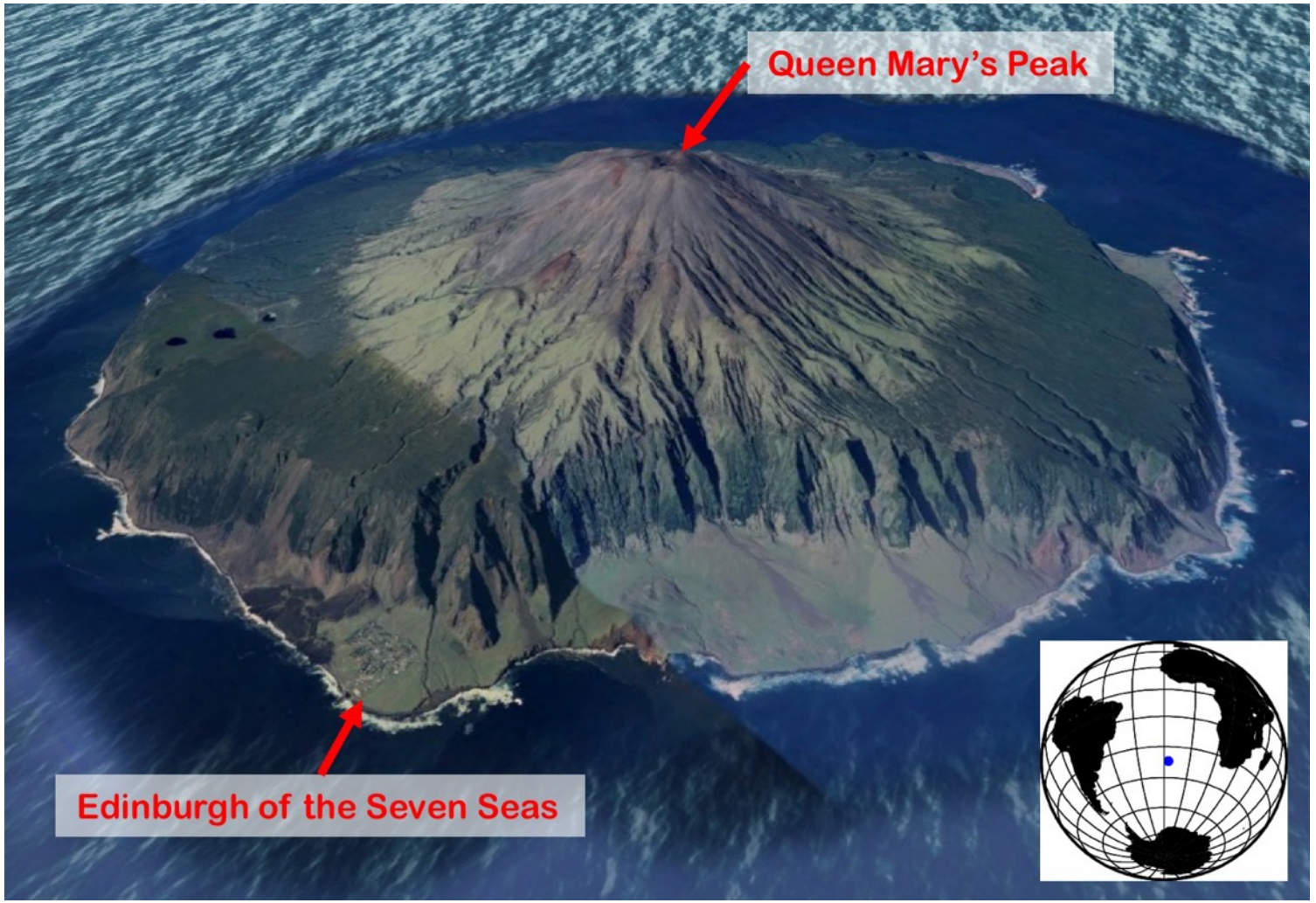


UK South Atlantic Tide Gauge Network

- Established since 1985
- British Overseas Territories (BOTs) and Antarctica
- Affords long sea level records from an under-sampled region
- Used for:
  - Monitoring ACC variability
  - ‘Ground truthing’ satellite altimetry
  - Understanding climate variability on various timescales incl. longer term changes
  - Design and testing of tide gauge (TG) equipment for remote and hostile locations

Tristan da Cunha Island

- Main island of the Tristan da Cunha archipelago
  - 4 islands (3+1)
  - Gough Island – 400 km south - IGS station (decommissioned)
- Near circular volcanic island with ~12 km diameter
- Volcano with highest point at ~2000 m
- Last eruption 1961
- ~260 Inhabitants



Tristan da Cunha - Logistics

- No flight option
- 5-day ship journey from Cape Town
- Extreme weather conditions with rough seas - landing is only possible on average on 60 days a year
- Little geospatial information, only satellite imagery
- International scientific interest (CTBTO, British Geological Survey, IGN/CNES and NOC-UL)

Daily Mail (2014)

Objectives

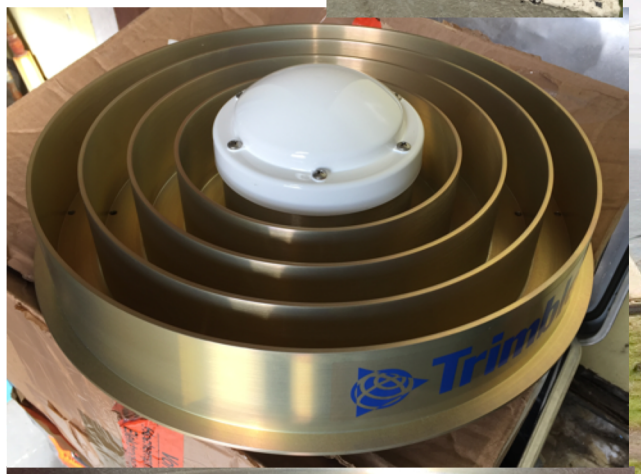
- Establish a scientific, state-of-the-art GNSS station to measure vertical land movements for sea level studies (IGS TIGA WG and GGOS Theme 3 missions)
  - Naturally GNSS enables a range of other scientific applications
- Establish two tide gauges to test which performs better in the remote location and hostile conditions: wave action
- Perform a site survey to reference
  - Tide gauges with respect to existing and new benchmarks
  - New GNSS Station TCTA (DOMES 30604M004) to current DORIS Station TRJB (DOMES 30604S003)

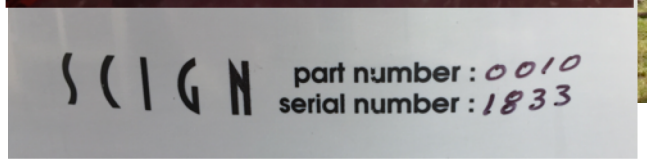

Orthophoto Drone Survey

GNSS Installation

- First attempt in 2016
- Success in 2017
- Trimble NetR9 and Trimble TRM59900.00 + SCIS radome (TCTA DOMES 30604M004)
- Antenna absolute calibration by Geo++ (GPS+GLONASS)
- Uses concrete pillar of decommissioned DORIS station TRIB
- RCV in enclosure with power and DSL Modem connected to comms box inside radio hut – LAN ready
- No data link at the moment !

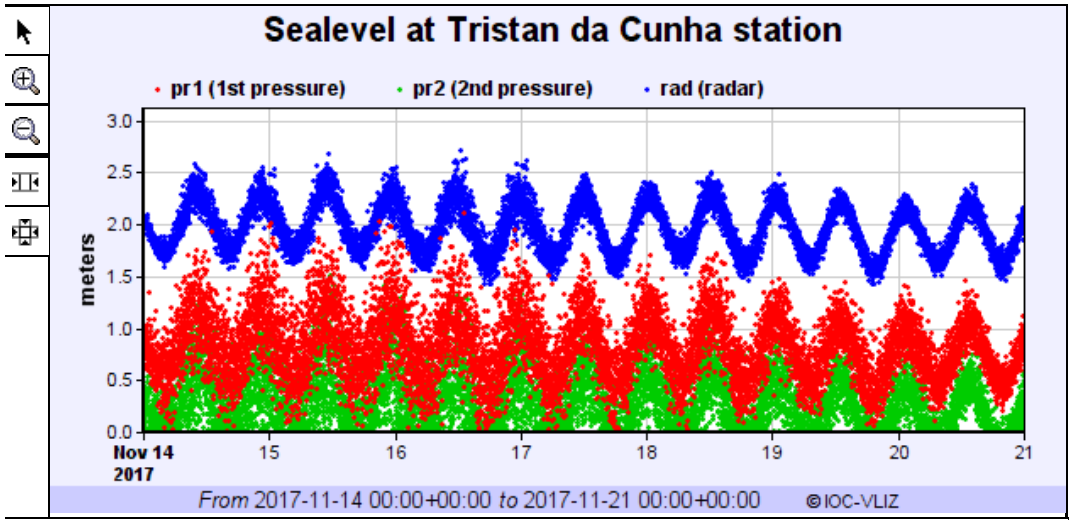
DORIS BM Station TRIB (DOMES 30604M001)



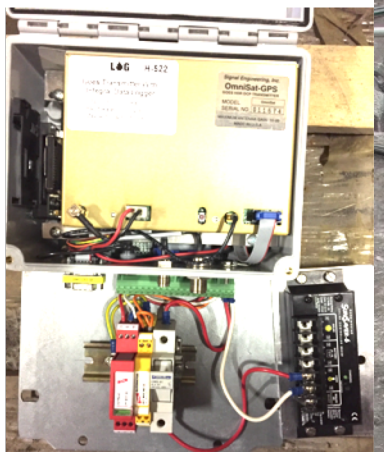


Tide Gauge Installations

- OTT Radar gauge + OTT pressure gauge with sensors at roughly full tide and half tide levels
- Data logger, power system and communication module in nearby boat shed

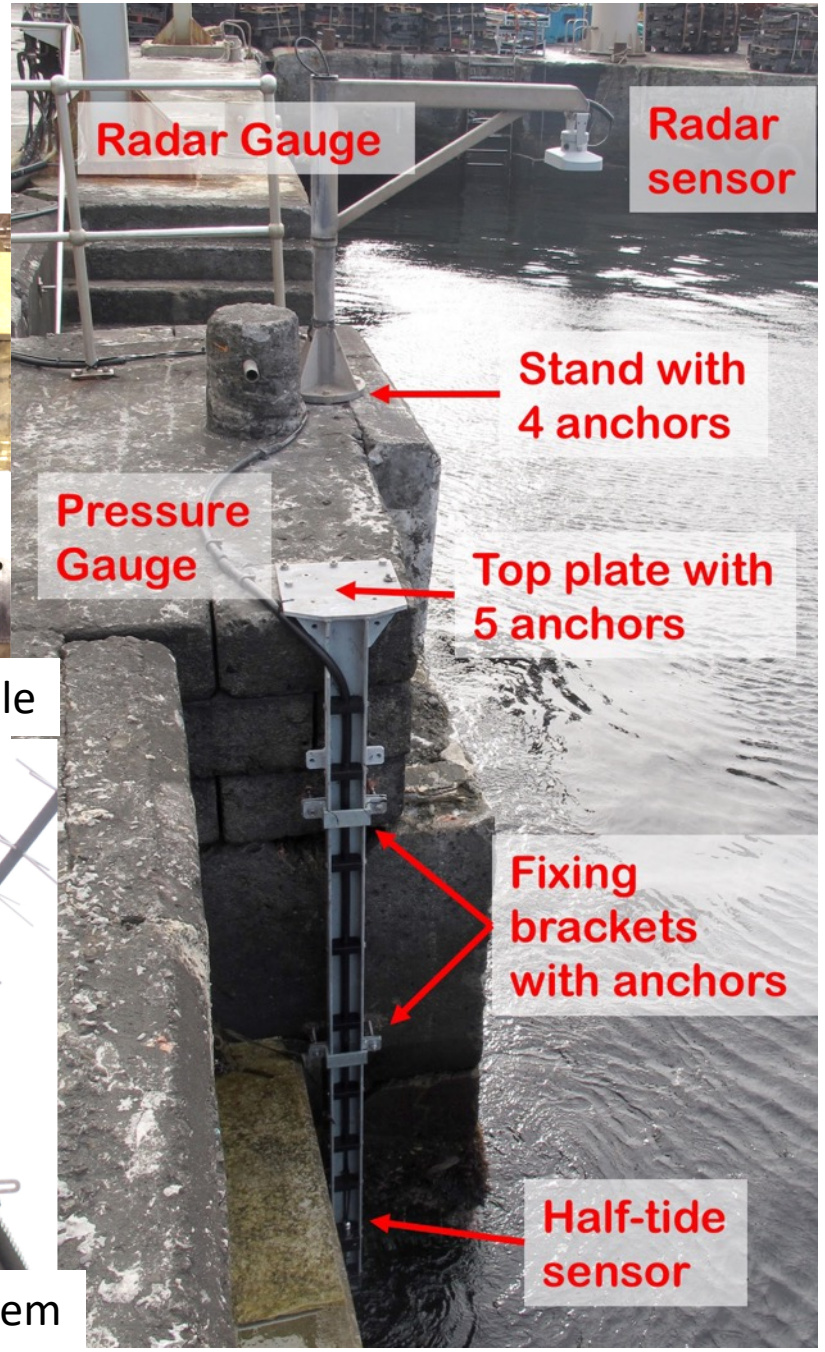


http://www.ioc-sealevelmonitoring.org/station.php?code=tdcu



Data Logger Module

Comms & Power System



Benchmark Network

▲ Tide Gauge Benchmarks

Benchmark Network

▲ Tide Gauge Benchmarks

Benchmark Network

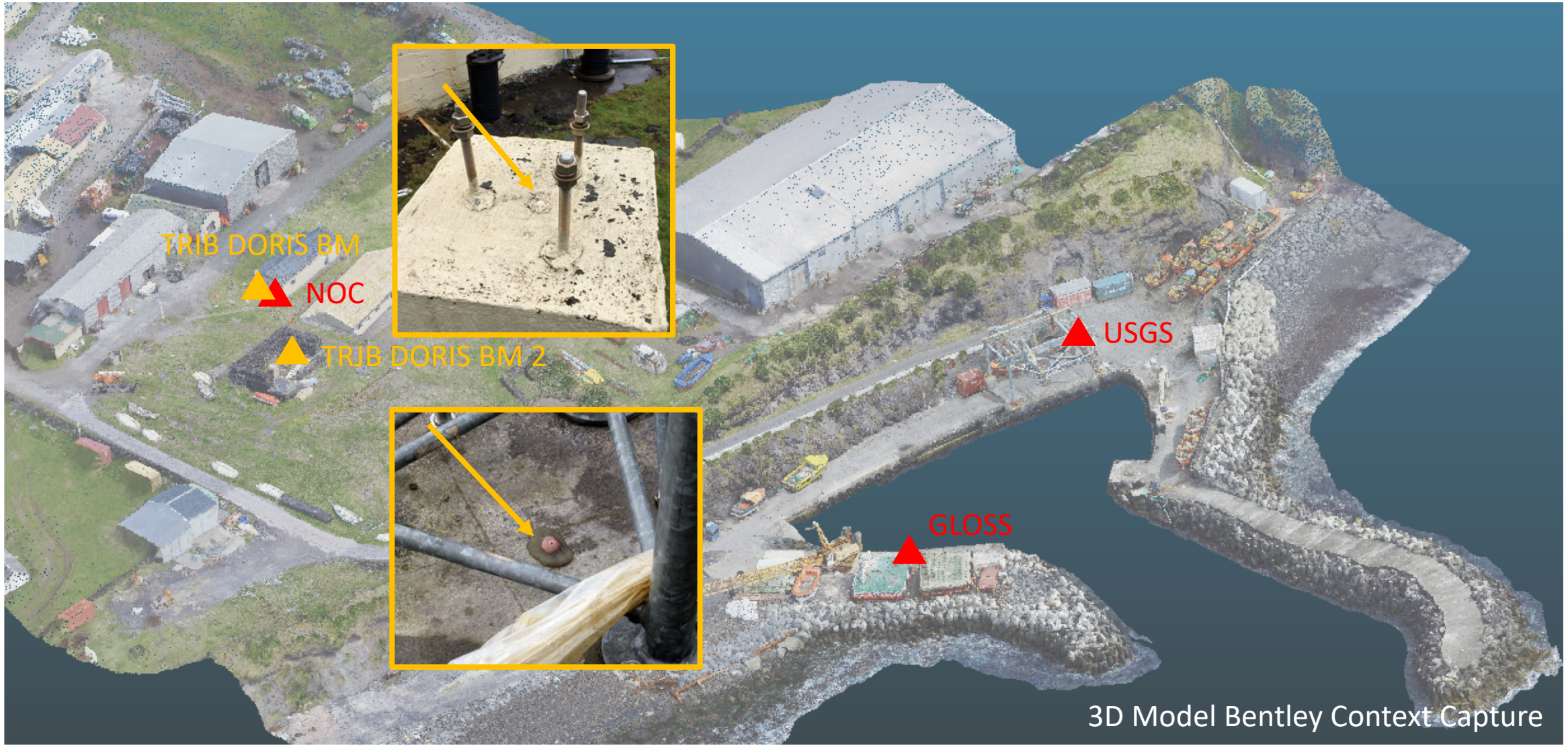
Tide Gauge Benchmarks

DORIS Benchmarks at TRJB and TRIB

Benchmark Network

Tide Gauge Benchmarks

DORIS Benchmarks at TRJB and TRIB

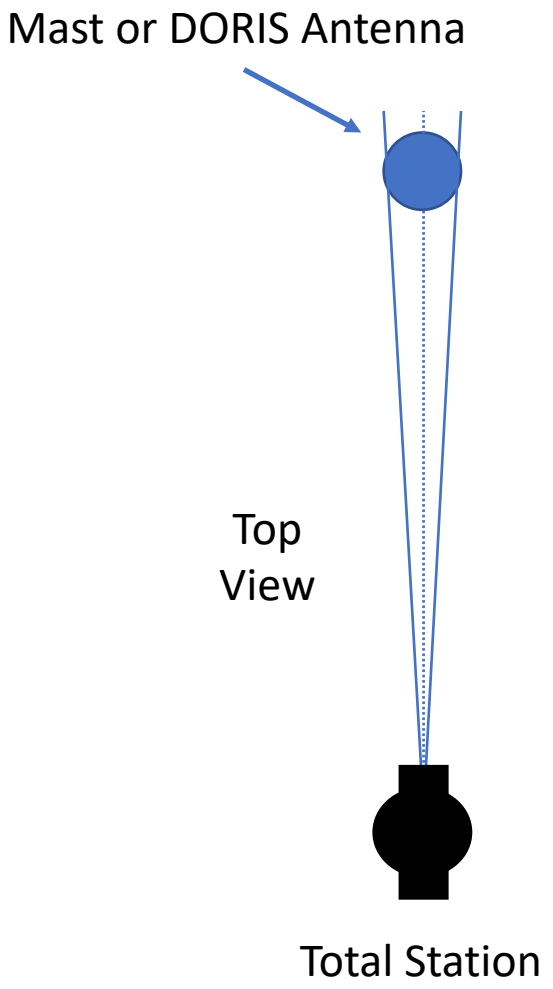


Benchmark Network

Tide Gauge Benchmarks
DORIS Benchmarks at TRJB and TRIB
GNSS/new Benchmarks

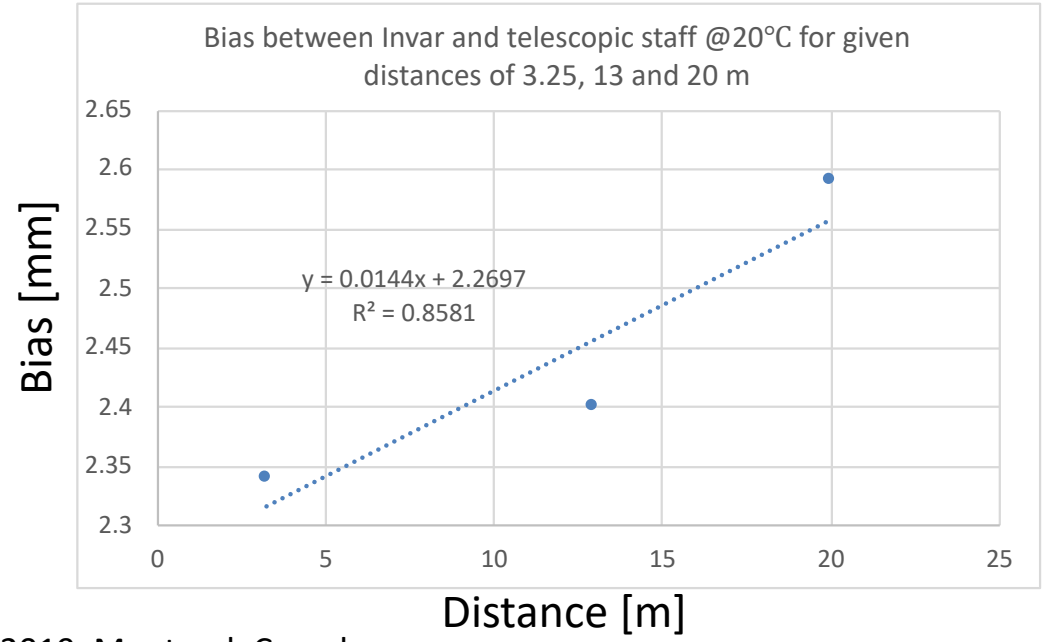
Site Survey

- Data Sets
  - 3 x 24 hours of GNSS observations at TCTA and 1003 (DoY 279-281, 2017)
    - To provide absolute position of TCTA and azimuth TCTA-1003
  - 1 x 1 hour of GNSS observations at 1002, 1003, 1004, 1005 and 1006
    - To provide approximate coordinates
    - Tripods remained in place for site survey (except at 1005)
  - Survey using Leica Total Station TS30
    - 3 full rounds of horizontal directions, vertical angles and slope distances
  - Precise levelling using Leica DNA03 and 3m Invar staff/3m telescopic staff
    - Differences between forward and backward runs <0.2mm
    - Bias between staffs when mixing of upright and inverted staff position
  - Drone photogrammetry and terrestrial laser scan for documentation purposes



Precise Levelling

- Mix of staffs
  - Normal levelling runs with 3m Invar staff – high accuracy
  - Sections to GNSS antenna, DORIS station and radar gauge with 3 m telescopic staff – lower accuracy
- Laboratory tests show bias between staffs when mixing upright and inverted position
- As a consequence, when using the telescopic staff, the height difference observed is too small, ~2,45 mm, sight distance dependent



Pre-processing and Least Squares Adjustment

Observation Pre-processing:

- GNSS 3-day solution of TCTA and 1003 (Azimuth) using Bernese GNSS Software v5.2
- GNSS 1-hour solutions of baselines TCTA to 1002, 1003, 1005 and 1006 using Leica GeoOffice v8.2
- Terrestrial survey data were pre-processed in rmGeo
  - Adjusted rounds of angles and slope distances
  - Averaged height differences
- Least Squares Adjustment using GeoLab 2017 V2017.2.6

PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
No. of Stations	32	Directions	34
Coord Parameters	70	Distances	21
Free Latitudes	19	Azimuths	0
Free Longitudes	19	Vertical Angles	0
Free Heights	32	Zenithal Angles	21
Fixed Coordinates	26	Angles	0
Astro. Latitudes	0	Heights	0
Astro. Longitudes	0	Height Differences	53
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	6	2-D Coords.	0
Direction Pars.	6	2-D Coord. Diffs.	14
Scale Parameters	0	3-D Coords.	6
Constant Pars.	0	3-D Coord. Diffs.	15
Rotation Pars.	0		
Translation Pars.	0		
	---		---
Total Parameters	76	Total Observations	164
Degrees of Freedom =	88		

Local Geodetic Datum Implementation

- Cartesian coordinates from TCTA and azimuth TCTA - 1003

```
*COORDINATE SOLUTION OF TCTA_ARP (IGS14/ITRF2014 EPOCH 2017:279)
*BERNESE GNSS SOFTWARE V5.2 PPP OVER 3 DAYS (DOYS 279-281)
 3DC
 XYZ  000 TCTA_ARP          4978463.5247     -1086616.9773    -3823205.2619   m  0
 COV  CT DIAG                      1
 ELEM               0.000001               0.000001               0.000001
```

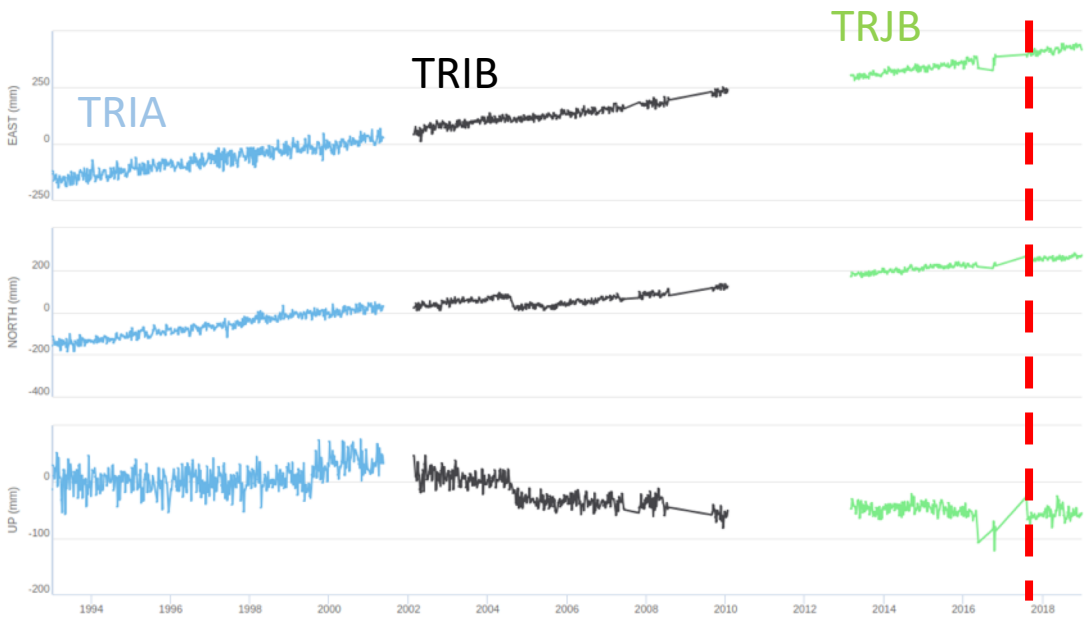
Average Coordinates for TCTA

```
*AZIMUTH DERIVED FROM TCTA_ARP AND 1003 (IGS14/ITRF2014 EPOCH 2017:279)
*BERNESE GNSS SOFTWARE V5.2 PPP OVER 3 DAYS (DOYS 279-281)
 3DD
 PLH  000 TCTA_ARP     S 37  3 55.000588 W 12 18 44.943277      47.9919 m       0
 PLH  000 1003_ARP     S 37  3 53.498850 W 12 18 44.188425      42.5524 m       0
 COV  LG DIAG
 ELEM               0.000001               0.000001                    0.01
```

Azimuth TCTA to 1003 over 3 days

DORIS TRJB Coordinate Observation DPOD2014 V1.0 @Epoch 2017 Doy 279

```
* PLH   000 TRJB          S 37   3 54.411577 W 12 18 44.639851       46.9286 m        0
 GRP   DORIS TRJB DPOD2014 V1.0 @EPOCH 2017.76164
 3DC
 XYZ   000 TRJB                4978474.98663     -1086611.80654     -3823190.13201 m   0
 COV   CT DIAG                        1
 ELEM                    0.0001                    0.0001                    0.0001
```



www.ids-doris.org

Centering Equations

- Various centering equations were introduced into the adjustment, e.g. at TCTA and TRJB

```
*TCTA_ARP AND CENTER OF MAST (1035) ARE VERTICALLY ALIGNED
 2DD
 PL   00  TCTA_ARP     S 37  3 55.000588 W 12 18 44.943277
 PL   00  1035         S 37  3 55.000588 W 12 18 44.943277
 COV  LG DIAG
 ELEM               0.000001                0.000001
```

```
*TCTA_ARP AND 1030 (TRIB DORIS BM) ARE NOT FULLY VERTICALLY ALIGNED
 2DD
 PL   00  TCTA_ARP     S 37  3 55.000588 W 12 18 44.943277
 PL   00  1030         S 37  3 55.000300 W 12 18 44.943076
 COV  LG DIAG
 ELEM              0.0000250               0.0000250
* PL   00  1030          S 37  3 55.000588 W 12 18 44.943277
```

Statistics Summary

Stochastic model:

- Errors from pre-processing where introduced a priori
- Variance factors of observation groups were equal at the beginning and updated accordingly:
  - GNSS vectors
  - DORIS coordinates
  - Height differences
  - Horizontal directions
  - Vertical Angles
  - Slope distances
- GeoLab 2017 uses theory for blunder detection as in Ghilani (2010)

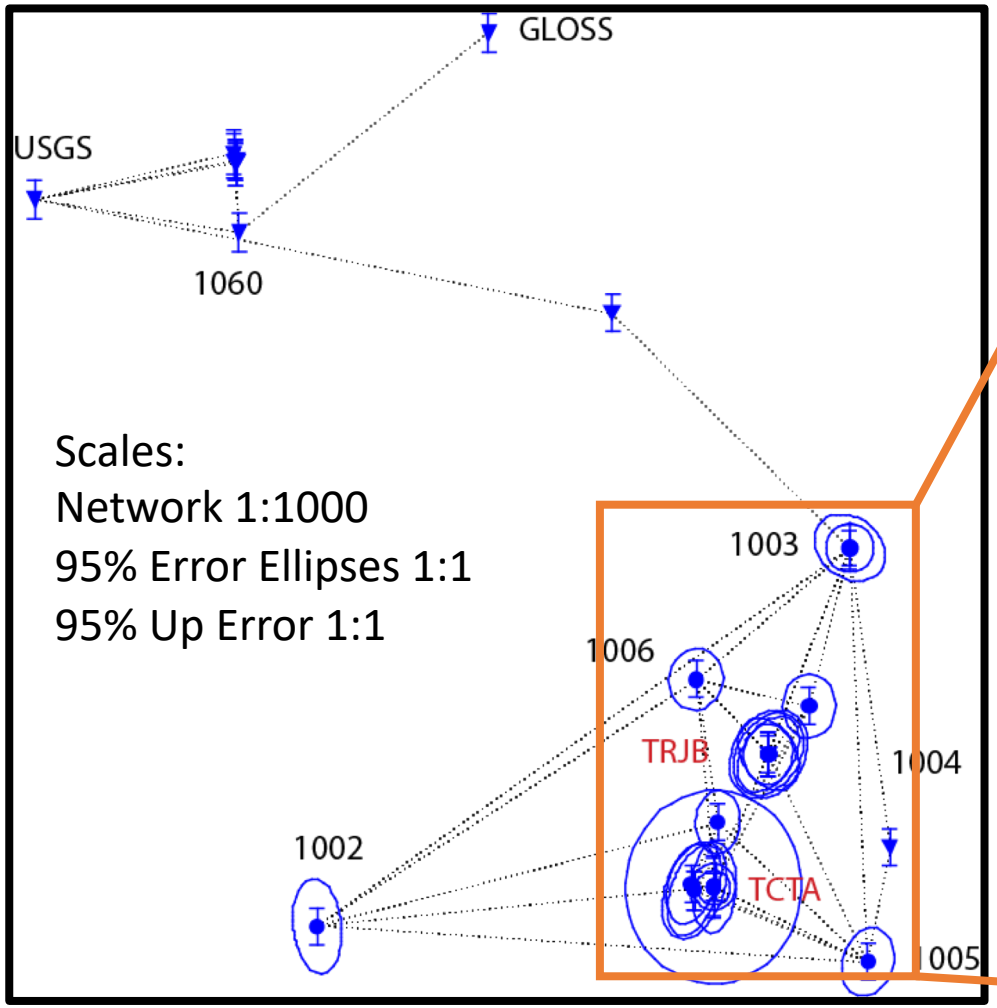
Residual Critical Value Type	Tau Max
Internal reliability	No
External reliability type	None
Reliability significance level	1.0
Reliability power of test	80
Residual Critical Value	3.6666
Number of Flagged Residuals	0
Convergence Criterion	0.0001
Final Iteration Counter Value	3
Confidence Level Used	95.0000
Estimated Variance Factor	0.9036
Number of Degrees of Freedom	88

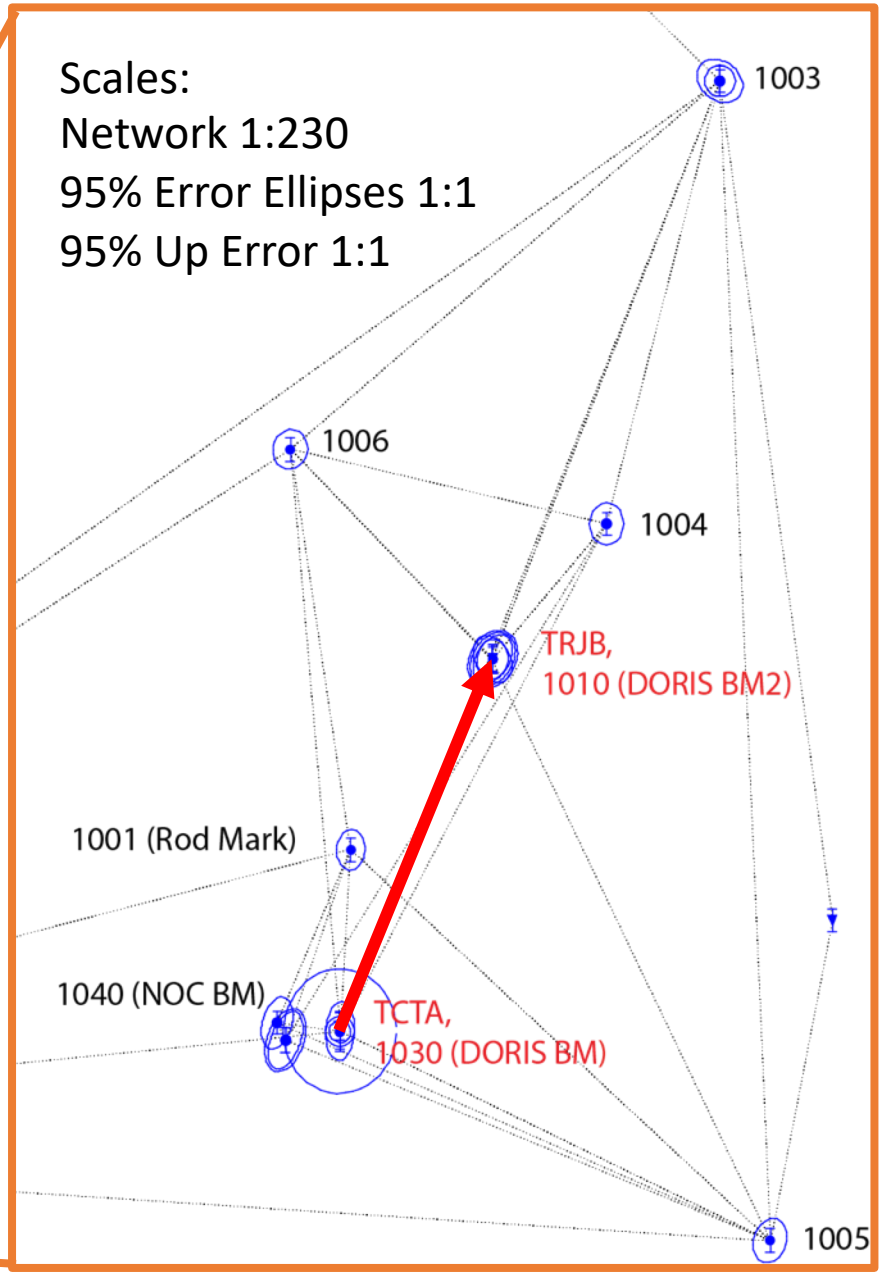
Chi-Square Test on the Variance Factor:

6.8646e-01 < 1.0000 < 1.2437e+00 ?

THE TEST PASSES

Network Solution





Extracted Main Coordinate Results (Co-location GNSS – DORIS)

CODE	FFF	STATION	X-COORDINATE STD DEV	Y-COORDINATE STD DEV	Z-COORDINATE STD DEV		
XYZ		TCTA_ARP	4978463.5247	-1086616.9773	-3823205.2619	m	0
			0.0009	0.0009	0.0009		
XYZ		TRIB	4978462.2906	-1086616.7026	-3823204.2916	m	0
			0.0038	0.0049	0.0045		
XYZ		TRJB	4978474.9572	-1086611.8044	-3823190.1433	m	0
			0.0020	0.0019	0.0020		
XYZ		TRJB2GHZ	4978475.3368	-1086611.8873	-3823190.4369	m	0
			0.0020	0.0021	0.0022		
XYZ		1010 (DORIS BM2)	4978472.2984	-1086611.2241	-3823188.0878	m	0
			0.0018	0.0016	0.0018		
XYZ		1030 (DORIS BM)	4978461.9077	-1086616.6190	-3823203.9956	m	0
			0.0022	0.0013	0.0023		

Using these we can cross-evaluate vector results from this study with the previous ones, Poyard (2012).

DORIS TRIB-TRJB Vector Cross-Evaluation

Benchmark	Poyard 2012			This Study			Difference			
Vector	**dX**	**dY**	**dZ**	**dX**	**dY**	**dZ**	**dX**	**dY**	**dZ**	**3D RMS**
DORIS BM - DORIS BM 2	10,3904	5,3951	15,9064	10,3907	5,3949	15,9077	-0,0003	0,0002	-0,0013	0,0013
	0,0027	0,0031	0,0030	0,0018	0,0021	0,0029				
DORIS BM - TRJB	13,0470	4,8182	13,8525	13,0495	4,8146	13,8522	-0,0025	0,0036	0,0003	0,0044
	0,0029	0,0031	0,0031	0,0030	0,0023	0,0030				
DORIS BM 2 - TRIB	-10,0074	-5,4787	-16,2025	-10,0078	-5,4784	-16,2038	0,0004	-0,0003	0,0013	0,0014
	0,0024	0,0028	0,0027	0,0042	0,0052	0,0048				
TRIB - TRJB	12,6647	4,9018	14,1486	12,6666	4,8981	14,1483	-0,0019	0,0037	0,0003	0,0042
	0,0027	0,0028	0,0028	0,0043	0,0053	0,0049				

All units are m.

- Sub-mm to -1,3 mm agreement for DORIS BM – DORIS BM2 vector.
- Overall 3D RMS ranges from 1,3 to 4,4 mm.

Extracted Main Levelling Results

CODE	FFF	STATION	LATITUDE	STD DEV	LONGITUDE	STD DEV	ELIP-HEIGHT	STD DEV	
PLH		TCTA_ARP	S 37 3 55.000588	0.0009	W 12 18 44.943277	0.0009	47.9920 m	0.0009	0
PLH		1001 (Rod Mark)	S 37 3 54.713534	0.0018	W 12 18 44.921636	0.0012	44.8213 m	0.0013	0
PLH		1010 (DORIS BM 2)	S 37 3 54.412446	0.0021	W 12 18 44.640022	0.0017	43.5017 m	0.0013	0
PLH		1030 (DORIS BM)	S 37 3 55.000193	0.0025	W 12 18 44.943065	0.0012	45.9071 m	0.0020	0
PLH		1040 (NOC Ball Mark)	S 37 3 54.987178	0.0023	W 12 18 45.068113	0.0014	44.5356 m	0.0013	0
PLH	110	GLOSS (Ball Mark)	S 37 3 51.222914	0.0000	W 12 18 46.192530	0.0000	24.4629 m	0.0013	0
PLH	110	1060 (BM)	S 37 3 52.103319	0.0000	W 12 18 47.577926	0.0000	25.5697 m	0.0013	0
PLH	110	USGS	S 37 3 51.958381	0.0000	W 12 18 48.712091	0.0000	25.4732 m	0.0013	0

Using these we can cross-evaluate height differences from this study with the previous ones, Poyard (2012).

Levelling Results – Cross-Evaluation

- Levelling results can be compared to two previous surveys in 2002 and 2012 (Poyard, 2012)

Benchmarks	N#	Elevation Differences [m]			Difference
		2002	Poyard 2012	This Study	2012-This Study
1030 (DORIS BM)	1				
1001 (Rod Mark)	2		-1,0840	-1,0858	0,0018
1040 (NOC Ball Mark)	3		-0,2860	-0,2857	-0,0003
1010 (DORIS BM 2)	4		-1,0350	-1,0399	0,0049
1050 (GLOSS Ball Mark)	5		-19,0310	-19,0388	0,0078
Total 1-5		-21,4600	-21,4360	-21,4502	0,0142
Total 2-5			-20,3520	-20,3644	0,0124
Direct 2-5 (no DORIS BMs)			-20,3515	-20,3584	0,0069
Direct 3-5 (no DORIS BMs)			-20,0656	-20,0727	0,0071

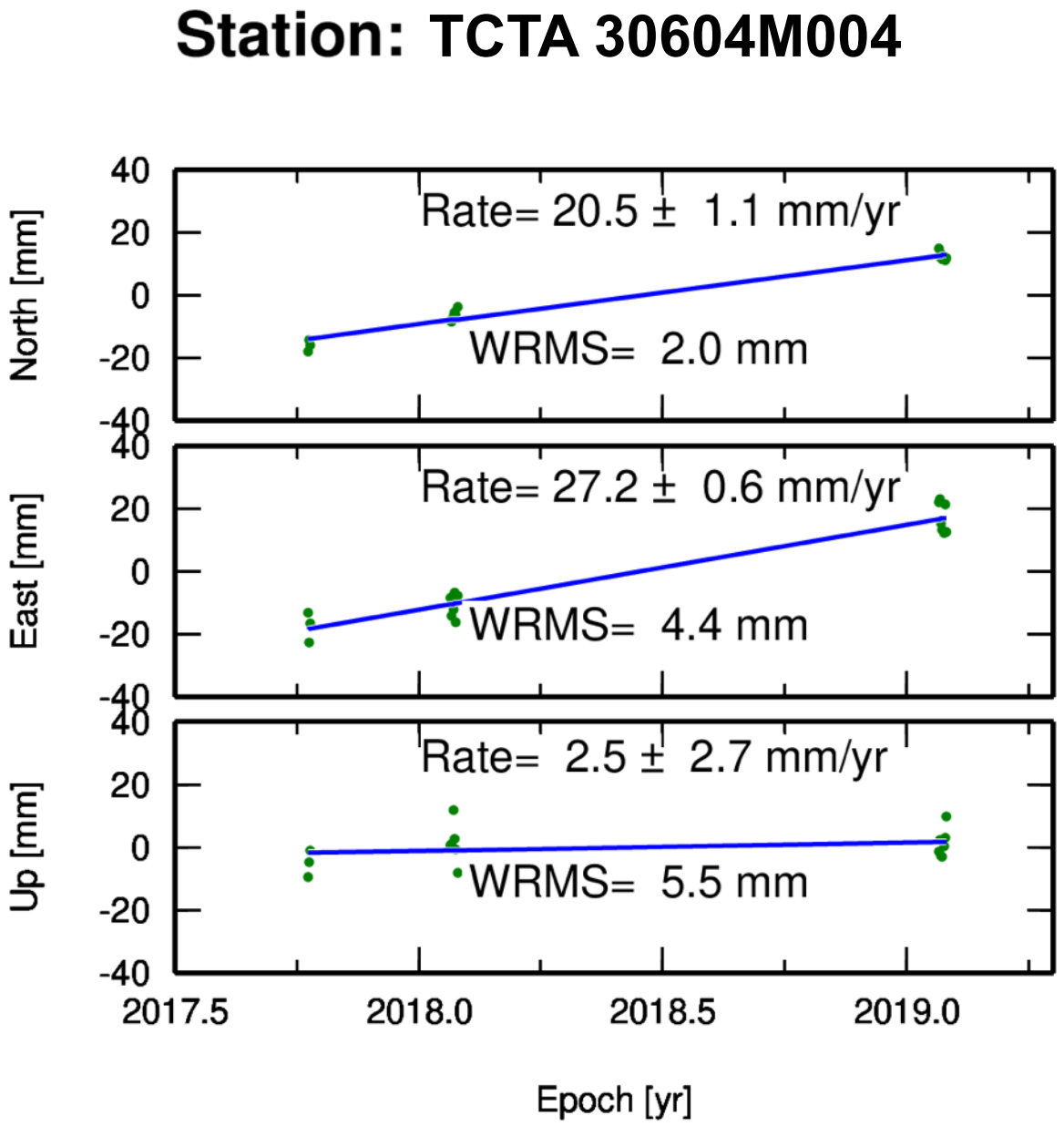
All units are m.

Conclusions

- The GNSS and tide gauge installations, the benchmark network and the site co-location survey on Tristan da Cunha have been presented
- The adjustment results have been cross-evaluated with the previous ones from Poyard (2012). This shows:
  - 3D RMS agreements of 1.3 to 4.4 mm for various vectors
  - Height differences between NOC BM – GLOSS BM of -20,0727 ± 0,0018 m, which differs by 7,1 mm from Poyard (2012).
- Cartesian coordinate vector TCTA_ARP – TRJB of dX= 11,4325 ± 0,0022 m
  dY= 5,1729 ± 0,0021 m
  dZ= 15,1186 ± 0,0022 m
- Height differences between the GNSS station and the new tide gauges have been determined at the few mm-level (not shown)
- For many GNSS@TG stations similar studies are missing / no levelling information is made available to the IGS TIGA Archive at www.sonel.org

Outlook

- Installation of dedicated satellite communications
- Once routine data communication has been established - application for inclusion as IGS station
- Contributions to the ITRF
- Unfortunately: a move of the GNSS station might become necessary once a new radio hut has been erected



Geodesy and Geospatial Engineering

Thank you for your attention!

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  - **Tristan da Cunha and Tristan da Cunha Administration**
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  - **National Oceanography Centre**
    - **Mr Peter R Foden**
  - **IGN, France**
    - **Dr Bruno Garayt, Mr Jean-Claude Poyard**

- **References**

  - **Donal, Th., July 2016, Ascencion ITRF Co-location Site Survey, IGN Report 28654.**
  - **Poyard, J-C., June 2012, Tristan da Cunha Co-location Survey, IGN Report 28431.**
  - **Ghilani, C.D., 2010, Adjustment Computations: Spatial Data Analysis, 5th Ed.**

Internal Vector Evaluation

- Several vectors can be evaluated for adhering to the given centering equations

Benchmark Vector	dN	dE	dU
TCTA_ARP - 1030 (DORIS BM)	0,0122	0,0052	-2,0849
TCTA_ARP - 1035 (TCTA_BCR)	0,0000	0,0004	0,0350
TRJB - 1010 (DORIS BM 2)	0,0000	0,0000	-3,4104
TRJB - TRJB2GHz	0,0000	0,0000	0,4870
1010RFL - 1010 (DORIS BM 2)	0,0051	-0,0017	1,2999

All units are in m.

- The solution suggests that
  - TCTA – DORIS BM are not vertically aligned
  - The handheld 1010RFL is not vertically aligned with DORIS BM 2.
  - There is no 3 mm East offset for TRJB – DORIS BM 2 (Poyard, 2012)

Tide Gauge Benchmark Heights

CODE	FFF	STATION	LATITUDE STD DEV	LONGITUDE STD DEV	ELIP-HEIGHT STD DEV	
PLH		1040 (NOC BALL MARK)	S 37 3 54.987178 0.0023	W 12 18 45.068113 0.0014	44.5356 m 0.0013	0
PLH	110	1050 (GLOSS BALL MARK)	S 37 3 51.222914 0.0000	W 12 18 46.192530 0.0000	24.4629 m 0.0013	0
PLH	110	1060 (New TGBM)	S 37 3 52.103319 0.0000	W 12 18 47.577926 0.0000	25.5697 m 0.0013	0
PLH	110	1061 (PG TOP PLATE)	S 37 3 51.792237 0.0000	W 12 18 47.593764 0.0000	24.7625 m 0.0013	0
PLH	110	1062 (PG PLATE BOLT)	S 37 3 51.790781 0.0000	W 12 18 47.601102 0.0000	24.7811 m 0.0013	0
PLH	110	1063 (RG MAINTENANCE)	S 37 3 51.780521 0.0000	W 12 18 47.592153 0.0000	25.8099 m 0.0013	0
PLH	110	1064 (RG OPERATION)	S 37 3 51.756197 0.0000	W 12 18 47.606775 0.0000	25.8234 m 0.0014	0
PLH	110	1070 (USGS BM)	S 37 3 51.958381 0.0000	W 12 18 48.712091 0.0000	25.4732 m 0.0013	0
PLH	110	PG_Sensor_1	S 37 3 51.792237 0.0000	W 12 18 47.593764 0.0000	21.7280 m 0.0016	0
PLH	110	PG_Sensor_2	S 37 3 51.792237 0.0000	W 12 18 47.593764 0.0000	22.2845 m 0.0016	0
PLH	110	RG_Sensor	S 37 3 51.756197 0.0000	W 12 18 47.606775 0.0000	25.5621 m 0.0017	0